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September 1981

Upgrading Unpaved Roads

Road Base Stabilization Using Lime and Fly Ash

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UPGRADING UNPAVED ROADS

ROAD BASE STABILIZATION USING LIME AND FLY ASH

Upper Plains States Innovation Group

UPGRADING UNPAVED ROADS

ROAD BASE STABILIZATION USING LIME AND FLY ASH

By: JACK HOWLEY
and
CHRIS WOHLERS

September, 1981

The Upper Plains States Innovation Group

UPSIG is a non-profit corporation formed in 1979 to introduce cost saving innovations into cities and counties in North and South Dakota, Montana, and Wyoming to help deal with everyday problems facing local government officials.

The league of cities and association of counties in Montana, North and South Dakota, and Wyoming each appoints a representative to the UPSIG Board of Directors. As such, UPSIG serves as the technology arm of these organizations. The Board of Directors selects UPSIG's project efforts, including the topic covered in this document. UPSIG is not a consultant, but rather addresses technical problems faced by many localities and attempts to bring about common solutions to these problems.

UPSIG is one of several "innovation groups" across the country which together form the National Innovation Network. These innovation groups share information on problems to avoid local government re-invention of the wheel and to ensure the transfer of useful local government technologies. Funding for the National Innovation Network comes from the National Science Foundation, Division of Intergovernmental Programs.

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PREFACE

This guidebook is intended for use by city and county roads superintendents in North and South Dakota, Montana, and Wyoming. It will also be of use to local governments in other rural parts of the nation.

This guidebook is for use by the practicing roads superintendent (city or county engineers, highway superintendents, etc.) faced with the decision of selecting the most cost-effective approach to upgrading an unpaved road. The material presented is intended to help determine if LFA base stabilization with an asphaltic surface seal is (or is not) a cost-effective approach for upgrading an unpaved local government road. The information provided will also be of value to the roads superintendent (if the decision is to proceed with an LFA stabilization project) in requesting bids and in following the progress of a first LFA stabilization project. It is not intended as a definitive handbook (or cookbook) on how to stabilize an unpaved road. It is not a substitute for experience.

In preparing this report, UPSIG relied on the expertise of many persons nationally; an advisory committee with representatives from universities, local government, consulting firms, and state and federal government agencies critically reviewed several drafts of this guidebook. We owe our appreciation to these persons and organizations for their involvement and viewpoints. However, UPSIG is solely responsible for the contents of this guidebook.

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LFA BASE STABILIZATION ADVISORY COMMITTEE MEMBERS

Tom Atkinson
Wyoming Highway Department
Materials Lab
Box 1708
Cheyenne, WY 82001

John Bilbro
Rosebud County Highway Supt.
Box 1117
Forsyth, MT 59327

Donald G. Fohs
Federal Highway Administration
(HRS-21)
Washington, DC 20590

John Frislie
Lincoln County Highway Supt.
P.O. Box 127
Canton, SD 57013

Gene Goeb, Chief Engineer
N-VIRO Energy Systems, LTD.
3450 W. Central Ave.
Suite 250
Toledo, OH 43606

Norman E. Henning, President
Twin City Testing Lab
662 Cromwell Ave.
St. Paul, MN 55114

Joe Hollingsworth
Sheridan County Engineer
P.O. Box 612
Sheridan, WY 82801

Dr. J. M. Hoover
Eng. Research Institute
101 A, Bldg. B
Iowa State University
Ames, IA 50010

Rick Kjonaas
Morton County Engineer
Box 277
Mandan, ND 58554

Roger Lee
Veigel Engineering
Box 937
Valley City, ND 58072

David Leer, Director
Experimental Projects Division
N.D. Highway Department
Bismarck, ND 58501

Dr. Oscar Manz
Coal By-Products Utilization Inst.
Box 8115
Grand Forks, ND 58202

Jeff Sommerfeld
Demonstration Projects Division
FHWA Region 15, Room 302
1000 N. Glebe Road
Arlington, VA 22201

Floyd Stanek
Federal Highway Administration
(HRS-14)
Washington, DC 20590

Mark Strong
National Minerals Corp.
Box 2028
Fargo, ND 58107

Richard Wegner
Chief, Materials Bureau
Montana Highway Department
2701 Prospect Ave.
Helena, MT 59601

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INTRODUCTION

Over 70% of this country's total road miles are unpaved; an average county road system in the Upper Plains region includes about 70-90% of unpaved road miles. In the past decade, road construction and maintenance costs have soared, road usage has risen, and local budgets have grown leaner. As a result, local officials and roads superintendents are searching for new approaches to improve the servicability of unpaved roads and to decrease their construction and maintenance costs.

Stabilization is a cost-effective approach to upgrading unpaved roads, and can improve the lifetime, strength, and riding surface of these roads. Because of the rising cost of petroleum-based products, stabilization can compare favorably with asphalt construction as an approach to upgrading unpaved roads. While several methods for stabilizing unpaved roads have been used by local governments throughout the country, one of the most promising methods is Lime - Fly Ash - Aggregate (LFA) stabilization. Depending on material and transportation costs, LFA stabilization can produce a road of equivalent strength and lifetime for less than (as much as one-half) the cost of asphalt construction; a significant savings considering asphalt construction costs in the neighborhood of $70,000 to $100,000 per mile.

A locality planning to upgrade an unpaved road should evaluate the advantages of LFA stabilization vs. alternative approaches (e.g. asphalt construction) for upgrading an unpaved road. Engineering requirements (especially the required load bearing capacity of the road) will dictate most of the costs for LFA stabilization and alternative approaches to upgrading.

The amount and cost of materials to meet the load bearing requirements of an LFA stabilization project will depend on the cost, quality and availability of lime, fly ash, and aggregate.

Maintenance costs for an LFA stabilized road will compare favorably with those for an asphalt constructed road.

LFA stabilization of unpaved roads has been used where increased traffic volume, inferior road materials, or adverse environmental conditions have required major improvements to the road. Stabilization of an unpaved road using lime, fly ash, and aggregate improves the load bearing capacity of the road base. Road aggregate is thoroughly mixed with lime, fly ash, and water to form a new road base to a depth of five or more inches. This new road base is then compacted and covered with an asphaltic surface layer such as a double chip seal. The upgraded road base continues to harden, or "set-up" over the next several months. An LFA stabilized road can eliminate dust problems, seasonal blading, washboarding and gravel loss, and improve the strength, durability, and riding quality of the road. Fly ash, a plentiful and generally inexpensive waste product of coal-burning power plants, can be obtained from private contractors or directly from the power plants. Lime can be obtained from commercial contractors.

LFA stabilization is not necessarily appropriate for a given road. Despite the proliferation of coal-burning power plants across the country (particularly in the West), not all local governments will have ready access (i.e. generally less than 50 miles) to sources of good quality, inexpensive fly ash; access to sources of inexpensive lime may also be a problem - hauling costs can escalate, making LFA stabilization impractical for some local governments.

This guidebook is intended to assist the local roads superintendent in evaluating the feasibility and costs of LFA stabilization for upgrading a candidate road. Starting from the engineering requirements of the road, the feasibility and approximate costs can be determined from an analysis of the construction requirements. The quality and costs of available lime, fly ash, and aggregate should be considered, as well as the mainten-

ance costs of LFA stabilization vs. the maintenance costs for alternative approaches for upgrading the road under consideration.

This guidebook also provides sufficient details on testing and construction procedures to allow the roads superintendent to request bids for, and to monitor, an initial LFA stabilization project. While this guidebook describes testing and construction procedures in some detail, it will not replace experience with LFA stabilization. For his first LFA project, the local roads superintendent should use the guidebook in conjunction with the professional services of an engineering firm or other qualified organization experienced with LFA stabilization. The guidebook is intended to help the roads superintendent play a constructive role during this first project - and to help prepare him to conduct subsequent LFA projects on his own.

SECTION 1. AN OVERVIEW OF LIME-FLY ASH STABILIZATION

Unpaved road stabilization is a technique for treating road base materials to improve the structural characteristics and riding quality of the road, and to decrease maintenance costs. In LFA stabilization of an unpaved road, lime, fly ash, and water are combined with the road base material. This mixture undergoes a chemical reaction (a pozzolanic reaction) that can produce a hard and durable base which can stand up to increased vehicle weights and volumes. An asphaltic surface layer (e.g. a chip seal) is always applied to an LFA stabilized road base. Under the right conditions, LFA stabilization of an unpaved road can eliminate dust problems, seasonal blading, washboarding and gravel loss, and improve the strength, durability and riding quality of the road. An LFA stabilized road base with an asphaltic surface seal can be a cost-effective approach to upgrading an unpaved road; the quality of the resulting road can equal alternative approaches to upgrading unpaved roads such as asphalt mats.

The Pozzolanic Reaction: "Pozzolans" are materials which, when combined with lime and water, undergo a chemical reaction that produces a cementing compound (see Figure 1). Fly ash is a pozzolan that is produced as a waste product of coal-burning power plants throughout the country (see Figure 2). Large quantities of fly ash are produced annually; because fly ash is a plentiful waste product, it is generally available for purchase at a reasonable cost (e.g. $15 per ton).

Not all fly ash is the same. Coal-fired power plants produce three general types of fly ash: 1) bituminous, 2) sub-bituminous, and 3) lignite. In the western region, lignite and sub-bituminous coals predominate, producing a fly ash with superior pozzolanic properties.

THE POZZOLANIC REACTION

LIME (calcium)	+	FLY ASH (silicas, aluminas)	+	WATER	=	A cementing compound capable of improving the strength and durability of unpaved roads.

When lime and fly ash are combined with water, a cementing compound capable of improving the strength and durability of unpaved roads is produced. When mixed with road aggregate, this cementing compound surrounds and locks the aggregate tightly in place, improving the strength and durability of the road.

The lime-fly ash-water reaction is called a pozzolanic reaction; the critical components are calcium (from lime and some fly ashes), and silicas and aluminas (from fly ash). The pozzolanic reaction requires "free" calcium, or calcium that is available to the reaction. Commercial grade hydrated lime contains mostly free calcium. Kiln dust contains proportionately less free calcium than commercial lime. Thus, greater quantities of kiln dust are required to produce a given strength and durability in a pozzolanic reaction than commercial lime.

Some fly ash also contains free calcium. However, depending on the type of fly ash, the amount of free calcium varies. The western fly ashes (from lignite and sub-bituminous coal) are significantly higher in free calcium than fly ash from other regions of the country. For this reason, LFA mixtures using western fly ashes commonly require less lime or kiln dust as a source of free calcium than mixtures using fly ash from other regions. Western fly ash mixtures also set up more quickly than do mixtures using lesser amounts of free calcium.

FIGURE 1. THE POZZOLANIC REACTION

Lime is produced commercially in plants throughout the country. There is one commercial lime plant in the upper plains region (see Figure 2). Lime is necessary to LFA stabilization because it contains free calcium, a critical component of the pozzolanic reaction (see Figure 1). An alternative source of free calcium is kiln dust, a waste product of lime and cement plants. Several of these plants are located in our region (see Figure 2). Kiln dust, however, typically contains much less free calcium than commercial lime. For this reason, to obtain a given strength and durability in an LFA stabilized road, a proportionately greater amount of kiln dust and lesser amount of fly ash must be used than in a mixture of commercial lime and fly ash.

The Product - A Stabilized Road Base: The pozzolanic reaction produces a cementing compound that surrounds and "locks" the road base material in place. The load bearing capacity (i.e. strength and durability) of an unpaved road can be significantly increased; the extent of the increase depends largely on the amount of base materials stabilized (i.e. depth of the road base), and the quality and the relative amounts of lime, fly ash, and road base materials which are used. An unpaved road that has been stabilized with LFA continues to gain strength (cures) over many years.

An LFA stabilized road base must be covered with a minimum asphaltic surface seal such as a double chip seal; an LFA stabilized road base will not cure properly without an asphaltic surface seal (moisture critical to the pozzolanic reaction will be lost through the surface). The surface seal will also protect the stabilized base from traffic abrasion and surface water infiltration.

Evaluating the Costs of LFA Stabilization: LFA stabilization is not a cure-all for local governments which are searching for low cost - high quality approaches to upgrading their unpaved

FIGURE 2: SOURCES OF POZZOLANIC MATERIALS

Adapted from:

1980 Keystone Coal Industry Manual; McGraw Hill Mining Publications; and materials provided by N-Viro Energy Systems, Ltd., 3450 W. Central Ave., Suite 250, Toledo, OH, 43606

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road systems. The technology is not always an economical approach to upgrading an unpaved road. Determination of the applicability of LFA stabilization for a given unpaved road will depend on its feasibility (the needed materials, equipment, and personnel resources may not be available) and the costs of LFA stabilization (materials, construction, and maintenance costs) vs. alternative approaches to upgrading (e.g. asphalt construction). Evaluating the costs of an LFA stabilization project is covered in the following section.

SECTION 2: ESTIMATING THE COSTS OF AN LFA STABILIZATION PROJECT

This section presents a general approach for determining the costs of a planned LFA stabilization project. Despite proven benefits, LFA stabilization may not be an economical alternative for upgrading a given unpaved road.

An LFA stabilization project may not be cost-feasible if there is not a reliable source of good quality fly ash or lime (or lime substitutes) within a reasonable distance of the job site. Additionally, if the local government does not have the necessary equipment or expertise to conduct an LFA project, the services of a contractor or consulting engineer will be necessary.

In selecting a cost-effective approach to upgrading an unpaved road, the life-cycle costs of each alternative approach should be considered; namely A) the materials costs and B) the construction and maintenance costs.

Since the costs of alternative approaches to LFA stabilization are generally familiar to the roads superintendent, this section addresses only the costs for an LFA stabilized road base.

Use of lime-fly ash for road stabilization at the local level falls into two major categories: 1) stabilization of the aggregate base and 2) stabilization of a mixture of the aggregate base and subgrade soil. As described in the preceding section, five to six inches or more of in-place aggregate is desirable for adequate lime-fly ash stabilization of roads with low traffic volumes. Often, however, in-place aggregate is less than this desired depth, requiring either additional aggregate or stabilization of a mixture of both aggregate base and subgrade soil to achieve desired load bearing capacities. LFA aggregate-soil base stabilization is described in Appendix A.

Estimating the costs for an LFA aggregate, or aggregate-soil base stabilization project requires consideration of the materials costs and the costs associated with construction and

maintenance. Namely:

- Determine the relative amount of each construction material (lime, fly ash, aggregate) necessary to achieve acceptable strength and durability values by testing several mix designs.
- Estimate the required thickness of the base course necessary to provide the needed structural strength for the road. Determine the total amounts and costs of the materials which will be needed.
- Cost out the construction procedures for mixing and spreading of construction materials, and for compacting, grading and sealing the stabilized base. Consider the requirements for properly maintaining the LFA stabilized road, including sealing of possible shrinkage cracks. Plan for the long-range protection of the capital investment in an LFA stabilized road.

A. MATERIALS COSTS

The need to upgrade an unpaved road arises when the original load bearing capacity* of the unpaved road is no longer adequate. Laboratory tests are performed on various percentage combinations of lime, fly ash, and aggregate to determine the appropriate combination (mix design) of these materials to yield acceptable compressive strength and durability values for the stabilized base. The required load bearing capacity (as specified by its structural number, or SN) of an unpaved road will

*Load bearing capacity is a measure of the strength and durability of a road. Whether determined by past experience or by sophisticated equations routinely used for state and federal roads, the required load bearing capacity dictates which mix designs are acceptable (or unacceptable) for a given road. Where quality lime, fly ash, and aggregate are available, LFA stabilization can usually meet the load-bearing requirements (structural number, SN) of a secondary road (see Table 1 - pg. 14).

then dictate the minimum depth for an LFA stabilized road base. This minimum depth, in turn allows a rough calculation of the total quantities of lime, fly ash, and aggregate needed for a project. The purchase price and transportation costs of these materials, along with the costs for an asphaltic prime coat and a minimum surface seal, will yield a rough estimate of the total materials cost to construct an LFA stabilized road base.

As with other approaches to upgrading an unpaved road, LFA stabilization of an unpaved road costs in the tens of thousands of dollars per mile. The LFA mix design should attempt to arrive at economical percentages of lime, fly ash and aggregate; a mix design calling for ten percent fly ash may, or may not, be economical depending on purchase and transportation costs. The roads superintendent should know the range of economical percentages of lime and fly ash before the mix design is determined in the laboratory. Similarly, a local government can spend too much or can risk significant losses in an expensive investment if the constructed LFA stabilized base is too thin or too thick. For these reasons the local government undertaking an LFA stabilization project may need to draw on engineering expertise from the state highway department, a university, or may need to contract with a consulting firm.

Construction Materials

Figure 3 presents a sample materials cost estimate. A materials cost estimate must consider the relative amounts of the materials needed (as determined in the mix design), the total amounts of these materials (thickness design) needed to meet the structural requirements of the road, and the purchase and transportation costs for these materials.

In addition to the costs for lime, fly ash and aggregate addressed in this section, an LFA stabilized road will also include the cost of a minimum protective asphaltic surface.

Materials costs for lime-fly ash stabilization are competitive with alternative approaches (see Table 2), and can produce a

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SAMPLE
LFA BASE STABILIZATION
MATERIALS COST ESTIMATE
WORKSHEET

Mix Design (by weight)
Lime: 2% Fly Ash: 10% Aggregate: 88% (in-place)

Thickness Design
6 inch depth (24 ft. wide road)
Volume of the base: 6" x 24 ft. x 5,280 ft. = 63,360 cu.ft./mile

Materials - quantity/cu.ft.
Weight of 1 cu.ft. of stabilized base = 135 lbs./cu.ft.(approx.)

Aggregate	88% x 135 lbs. =	118.8 lbs./cu.ft. of base
Fly Ash	10% x 135 lbs. =	13.5 lbs./cu.ft. of base
Lime	2% x 135 lbs. =	2.7 lbs./cu.ft. of base
		135.0 lbs./cu.ft. of base

Materials - quantity/mile
At 63,360 cu.ft./mile

Aggregate	118.8 lbs./cu.ft. x 63,360 cu.ft. =	3,764 tons
Fly Ash	13.5 lbs./cu.ft. x 63,360 cu.ft. =	428 tons
Lime	2.7 lbs./cu.ft. x 63,360 cu.ft. =	85 tons

Materials Cost

Aggregate	In-place	$ -0-	
Fly Ash	428 tons at $15/ton	6,420.	
	" " @ 10¢/mi. x 35 mi.	1,498.	
Lime	85 tons at $60/ton	5,100.	
	" " @ 10¢/mi. x120 mi.	1,020.	
			$14,038./mile
Primer Coat		5,300.	
Double Chip Seal		15,000.	
			20,300./mile
	TOTAL		$34,338./mile

FIGURE 3

road with load bearing capacities equal to, or greater than, other approaches (see Tables 1 & 2). Transportation costs, however, are a major factor in determining the cost of LFA stabilization. As a general rule, hauling distances greater than 50-60 miles may reduce the competitiveness of LFA stabilization.

While the purchase price of lime and fly ash varies by region, the average purchase price for lime is $60/ton at the plant (± $3/ton); for fly ash, $10-$15/ton at the power plant. Transportation costs also vary, but 9¢-10¢ per ton/mile (or about $5/ton for a 50 mile haul) is an average.

The quality of available materials (including aggregate, lime and fly ash) will affect the relative amounts of these materials needed. By example, a well graded aggregate (i.e. many different particle sizes) requires less lime and fly ash to achieve a given strength than a poorly graded aggregate. Some fly ashes are particularly good for stabilization, others are particularly poor. The same holds true for lime. Appendix B describes preferred properties of aggregate, fly ash and lime in greater detail as well as standard tests for measuring these properties.

LFA Mix Designs and Testing: In selecting the mix of lime, fly ash and aggregate to be used on a project, several mix designs (i.e. several combinations of lime, fly ash and aggregate in varying percentages) are tested to determine the strength and durability of these various mixes. The LFA mix designs are laboratory tested for compressive strength and durability (residual compressive strength following vacuum saturation). In colder climates, compressive strengths in the range of 600-1,000 psi* after curing for seven days indicate a good quality LFA mix. (These strengths will continue to increase over the following

*ASTM Testing procedure C593 notes 400 psi as a minimum compressive strength for an acceptable mix.

PAVEMENT DESIGN COST COMPARISON

BY

LOAD BEARING CAPACITY (SN) CATEGORIES

Structural Number (SN)	Design		Cost/Sq.Yd.
	Surface	Base	
1.54	2" Asphalt	6" Stone Base	$ 6.14
1.57	Double Seal	5" KD/LFA/Aggr.	5.40
1.75	1" Asphalt	5" KD/LFA/Aggr.	5.96
1.90	Double Seal	6" KD/LFA/Aggr.	6.26
2.10	2" Asphalt	4" Asphalt Base	10.38
2.10	2" Asphalt	5" KD/LFA/Aggr.	7.77
2.17	3" Asphalt	8" Stone Base	8.79
2.20	1-1/2" Asphalt	6" KD/LFA/Aggr.	7.70
2.20	Double Seal	7" KD/LFA/Aggr.	7.09
2.73	3" Asphalt	6" KD/LFA/Aggr.	10.41
2.80	3" Asphalt	5" Asphalt Base	13.88
2.80	4" Asphalt	10" Stone Base	11.44
2.83	2-1/2" Asphalt	7" KD/LFA/Aggr.	10.34
3.43	3" Asphalt	8.5" KD/LFA/Aggr.	12.49
3.43	5" Asphalt	12" Stone Base	14.09
3.50	3" Asphalt	7" Asphalt Base	17.26

Comparison of Cost and Design

Each design listed above has a corresponding structural number (SN); the SN can be considered a general indicator of the load bearing capacity (i.e. strength and durability) of each design. A general classification of categories of roads and required SN values are as follows:

Structural Number (SN)	Road Category
1.5 - 2.0	Light traffic; residential
2.0 - 3.5	Low to moderate traffic; arterial and feeder roads
3.5 above	High volume traffic; primary roads

TABLE 1

Adapted from: Materials provided by N-Viro Energy Systems, Ltd., 3450 W. Central Ave., Suite 250, Toledo, OH 43606. Structural Numbers (SN) derived from Ohio Highway Dept. guidelines.

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COMPARATIVE COSTS OF PAVING MATERIALS

Material Cost Only

Material	Cost/Ton	Cost/Sq.Yd 1" of Pavement Depth (% by wt.)
Crushed Stone	$ 5.50	$ 0.31
Lime	62.00	0.12 (3.5% Addition)
Fly Ash (FA)	15.00	0.10 (12% Addition)
Kiln Dust (KD)	15.00	0.07 (8.0% Addition)
Fly Ash (FA)	15.00	0.07 (8.0% Addition)
Asphaltic Base	200.00	0.56 (5.0% Content)
Asphaltic Surface	200.00	0.67 (6.0% Content)

In Place Cost

Paving Material	Cost/Cu.Yd.	Cost/1"/Sq.Yd.
Crushed Stone	$15.00	$ 0.42
Lime/FA/Aggr.	32.00	0.89
Kiln Dust/FA/Aggr.	29.00	0.83
Asphaltic Base	61.00	1.69
Asphaltic Surface	65.00	1.81
Double Asphalt Seal	N/A	1.25/.75"/sq.yd.

Assumed Costs

The costs used are an average of a wide range of costs (as of Spring 1981) in various areas, and are based on central plant mix operations; in-place mixing will lower costs. Costs will vary according to local materials availability and transportation costs. The more significant fact to note is the relationship between the costs of the various paving materials. The actual cost of individual paving materials and the total cost of a specific pavement design may vary substantially from one location to another. The relationship of the costs of various pavement designs when compared one to another, however, will generally remain the same.

TABLE 2

Adapted from: Materials provided by N-Viro Energy Systems, Ltd., 3450 W. Central Ave., Suite 250, Toledo, OH 43606.

months.) Residual strength following vacuum saturation testing is a good indicator of durability; that is, ability to "hold form" under repeated freeze-thaw cycles, a critical measure in regions with cold winter climates. Residual strengths of 50-60% are acceptable. ASTM C593* is the laboratory testing procedure used to determine the strength gain and durability of the alternative LFA mix designs.

Figure 4 illustrates the steps from initial mix design considerations through the testing procedures for determining the strength gain and durability of the LFA mix. Local roads superintendents should be familiar with the reasons for these steps; other than specifying economic constraints on percentage values for the lime, fly ash, and aggregate for the LFA mix, local personnel should not feel it necessary to understand the specific methods or theories underlying these steps.

Thickness Design

The selected LFA mix design will specify the percentages of lime, fly ash, and aggregate to be used in the stabilization project. Once an acceptable LFA mix design has been selected, the required thickness of the LFA stabilized base will have to be estimated in order to calculate the total amount of lime and fly ash (and supplemental aggregate, if necessary) which will be needed for the project.

A simplified approach to estimating the required thickness of the LFA stabilized base is to determine the equivalent thick-

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*This testing procedure can also serve to identify potential shrinkage and expansion of the LFA mix as it cures over time. The severity of shrinkage/expansion can be estimated by measurement of the change, if any, in dimensions (i.e. height, width) of the test cylinders after the seven day curing period. Shrinkage is a common characteristic of reactions involving cementitious materials (i.e. LFA). LFA mix shrinkage, however, is typically not as serious a problem as with soil cements (e.g. portland cement mixes). Expansion of an LFA mix may be directly related to the degree of fly ash reactivity; fly ashes with high calcium oxide content seem particularly vulnerable to expansion.

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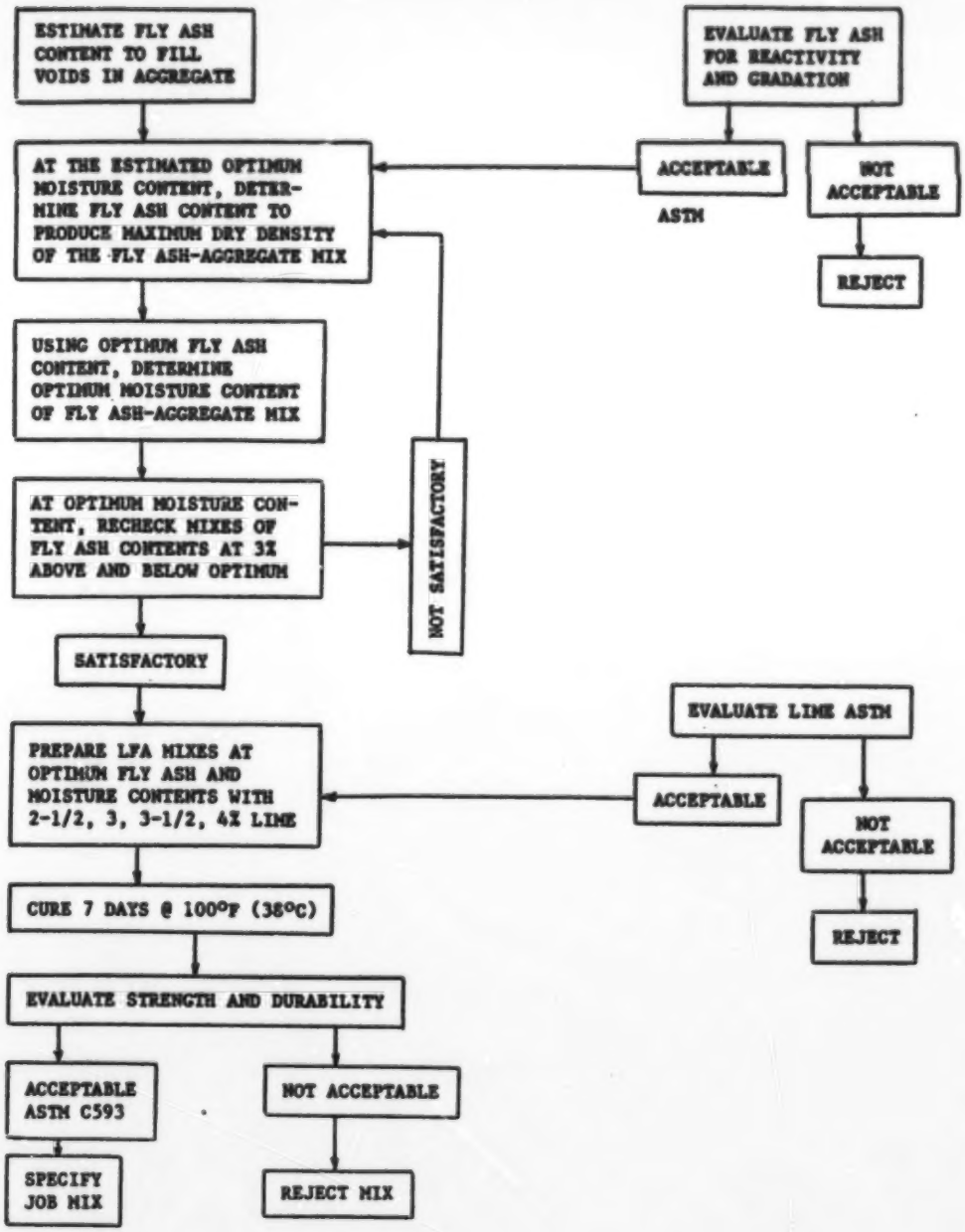
ESTIMATE FLY ASH CONTENT TO FILL VOIDS IN AGGREGATE
EVALUATE FLY ASH FOR REACTIVITY AND GRADATION
ACCEPTABLE
ASTM
NOT ACCEPTABLE
REJECT
AT THE ESTIMATED OPTIMUM MOISTURE CONTENT, DETERMINE FLY ASH CONTENT TO PRODUCE MAXIMUM DRY DENSITY OF THE FLY ASH-AGGREGATE MIX
USING OPTIMUM FLY ASH CONTENT, DETERMINE OPTIMUM MOISTURE CONTENT OF FLY ASH-AGGREGATE MIX
AT OPTIMUM MOISTURE CONTENT, RECHECK MIXES OF FLY ASH CONTENTS AT 3% ABOVE AND BELOW OPTIMUM
NOT SATISFACTORY
SATISFACTORY
EVALUATE LIME ASTM
ACCEPTABLE
NOT ACCEPTABLE
REJECT
PREPARE LFA MIXES AT OPTIMUM FLY ASH AND MOISTURE CONTENTS WITH 2-1/2, 3, 3-1/2, 4% LIME
CURE 7 DAYS @ 100°F (38°C)
EVALUATE STRENGTH AND DURABILITY
ACCEPTABLE ASTM C593
NOT ACCEPTABLE
SPECIFY JOB MIX
REJECT MIX

FIGURE 4. MIXTURE DESIGN FLOW DIAGRAM

From: Soil Stabilization in Pavement Structures: A User's Manual; Vol. 2, Mixture Design Considerations. R. Terrel, J. Epps, E. Barenberg, J. Mitchell, and M. Thompson. Prepared for: Federal Highway Administration. October 1979 (p. 62).

ness of an asphalt mat which could alternatively be used to upgrade (i.e. improve the structural strength) the road in question. This thickness of asphalt corresponds to a structural number (strength and durability). The required thickness of a stabilized LFA base must also meet this structural number.

Keep in mind, though, that an asphalt mat would be placed on top of the in-place aggregate; this in-place aggregate also contributes to the structural number of the road. If this aggregate is to be scarified and mixed in-place with lime and fly ash, then the "removal" of this aggregate for use in the LFA mix must be taken into consideration.

Figure 5 presents an approach which can be used to estimate the required thickness of an LFA stabilized base, assuming that the required equivalent thickness of asphalt is known and that this thickness of asphalt would meet the upgraded structural number (strength and durability) requirements of the road. If more than a minimum thickness (i.e. chip seal) of an asphaltic surface seal will be placed on the stabilized base, then the structural value of this mat will correspondingly reduce the thickness design of the stabilized base.

B. CONSTRUCTION AND MAINTENANCE COSTS

The manpower and equipment costs for upgrading and maintaining a road with an LFA stabilized base will vary from one locality to another. These costs may also vary depending on whether a contractor is used and whether in-place vs. central plant mixing is used. As on any road project, the costs will also vary depending on the productivity of the men and equipment used.

This section does not attempt to give the reader a detailed approach to costing construction and maintenance for an LFA stabilized road, but rather describes the necessary procedures and equipment to perform these functions. The local roads superintendent will, hopefully, then be able to estimate these costs

ESTIMATING THE REQUIRED THICKNESS OF AN LFA STABILIZED BASE

$$T = \frac{A \cdot B + (0.1\ C)}{0.28}$$

Where:

T = Required thickness of the LFA stabilized base

A = Thickness of the asphalt mat which would alternatively be placed if LFA base stabilization were not used

B = Structural coefficient for the grade of the asphalt mat which would alternatively be placed. Several states use 0.3 for asphaltic base material and 0.4 for surface grade hot mix. Check with your state highway department for the proper coefficient to use in your state.

0.1 = Structural coefficient for in-place aggregate base

C = Thickness of in-place aggregate base which will be scarified for use in the LFA stabilized base.

0.28 = Structural coefficient for good quality LFA stabilized base material (compressive strength of 600-1000 psi)

EXAMPLE:

A = 5; five inches of surface grade hot mix would have been used as an alternative to LFA base stabilization

B = 0.4; coefficient for surface grade hot mix

C = 4; four inches of in-place aggregate to be scarified. Several more inches of aggregate to be hauled in

$$T = \frac{5 * 0.4 + (0.1 * 4)}{0.28} = 8.5 \text{ inches}$$

FIGURE 5

for a given project. These procedures will also be of value in requesting bids and in monitoring, or guiding, a first LFA stabilization project. The procedures for stabilizing a road base with a mixture of in-place aggregate and subgrade soil are covered in Appendix A.

Construction Procedures

Construction procedures for an LFA stabilized road base include mixing and spreading, compacting, grading and surface sealing. *Experience in LFA base stabilization construction procedures are critical to the outcome of the project. If the local roads crew does not have experience in this process, a contractor that does should be carefully selected.*

Local roads departments may find that they have the in-house equipment needed for LFA stabilization, particularly if in-place mixing operations are used. For the most part, LFA stabilization projects conducted at the local level have used conventional road equipment (equipment needs are described later). LFA stabilization should be undertaken only during the warmer months of the construction season and well before the winter months (see Figure 6); the pozzolanic reaction effectively stops when temperatures drop below freezing.

Adequate drainage is a very important factor in LFA road stabilization. Water must not be allowed to stand on the road; a good surface crown and ditch line are critical to proper drainage and reduction of upward water infiltration from the water table (see Figure 7). Without attention to the configuration of the road surface and ditch lines, the ultimate lifetime of the stabilized road may be significantly lowered.

The condition of the subgrade material (working platform) is an important factor in attaining a densely compacted LFA mix. LFA mixes spread and compacted on a soft subgrade will shove rather than be tightly compacted. Plastic clays typically are poor subgrades for LFA stabilized roads; pretreatment of plastic clay subgrade soils with lime will result in significant reduc-

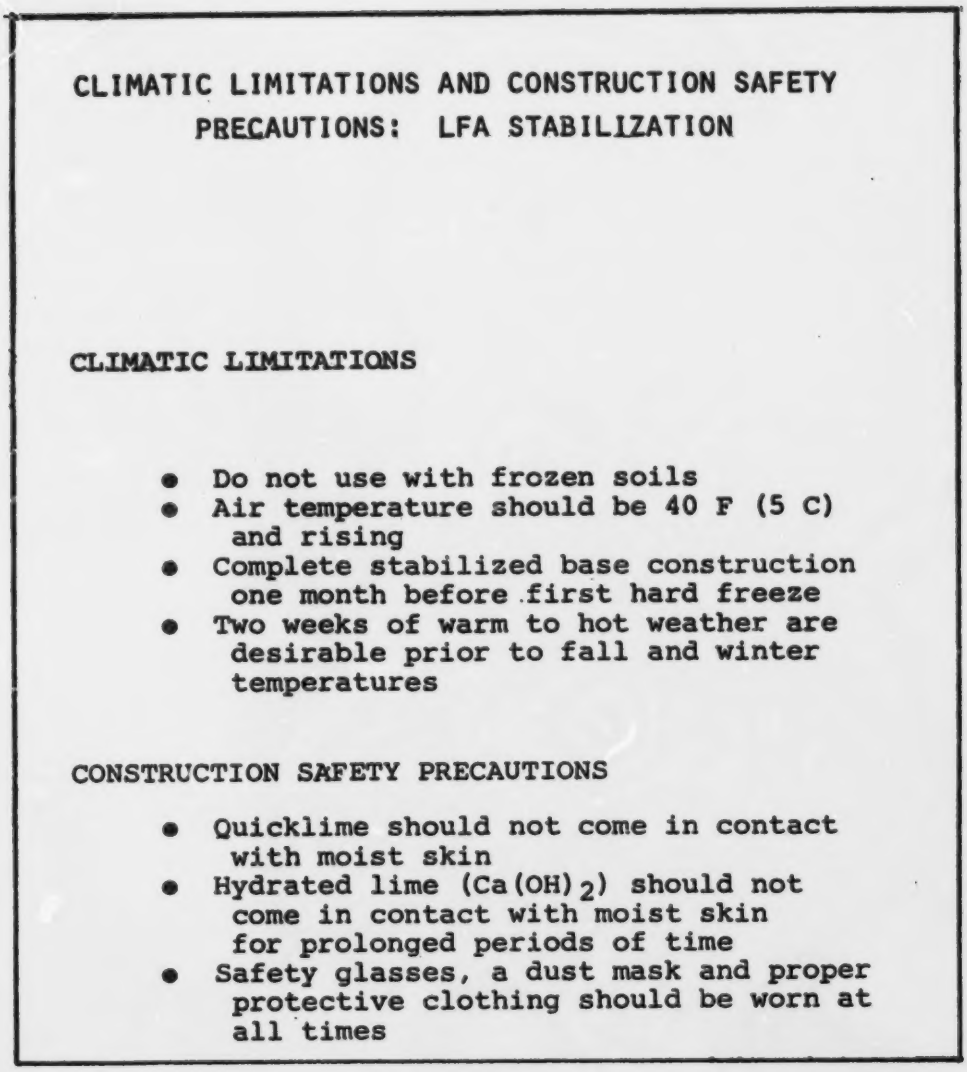
CLIMATIC LIMITATIONS AND CONSTRUCTION SAFETY PRECAUTIONS: LFA STABILIZATION
CLIMATIC LIMITATIONS
• Do not use with frozen soils
• Air temperature should be 40 F (5 C) and rising
• Complete stabilized base construction one month before first hard freeze
• Two weeks of warm to hot weather are desirable prior to fall and winter temperatures
CONSTRUCTION SAFETY PRECAUTIONS
• Quicklime should not come in contact with moist skin
• Hydrated lime ($Ca(OH)_2$) should not come in contact with moist skin for prolonged periods of time
• Safety glasses, a dust mask and proper protective clothing should be worn at all times

FIGURE 6. CLIMATIC LIMITATIONS AND CONSTRUCTION SAFETY PRECAUTIONS.

Adapted from: Soil Stabilization in Pavement Structures: A User's Manual; Vol. 2, Mixture Design Considerations. R. Terrel, J. Epps, E. Barenberg, J. Mitchell, and M. Thompson. Prepared for: Federal Highway Administration. October 1979 (p. 26).

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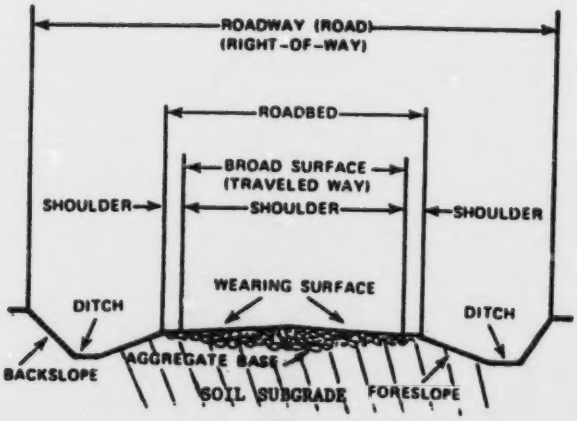

FIGURE 7. TYPICAL SECTION OF AGGREGATE SURFACED ROADWAY

Adapted from: Road and Bridge Guidebook; the Center for Local Government Technology, Division of Engineering, Technology and Architecture; Oklahoma State University (p. 55).

tion of soil plasticity (eliminating the "shoving" problem), providing an adequate working platform for LFA base stabilization.

LFA stabilized roads must be sealed (asphaltic chip seals, asphaltic mats, etc.). Many local government projects have used single or double layer chip seals to protect LFA stabilized secondary roads. An asphaltic chip seal is generally the least expensive protective surface ($5,000 to $10,000 per mile for a 3/8" chip seal).

Mixing and Spreading

Highly reactive fly ash should not be open-stockpiled. It can be bulk-stored in a dry state in silos or brought directly from the power plant to the job site. Lime, too, should not be open-stockpiled, but can be stored either in silos or transported to the job site on an as-needed basis.

Construction of an LFA stabilized road can involve in-place (i.e. on the road) or central plant mixing of lime, fly ash, aggregate, and water (see Figure 8 - page 25). In-place mixing is a less expensive option. Central plant mixing produces a higher quality stabilized road base (i.e. more thorough mixture of materials and greater precision in measuring quantities of each material), but at a higher cost. Which of these approaches is used will depend on: 1) the availability of equipment, and 2) distance from the lime and fly ash sources to the job site and/or the central plant. Both central plant and in-place operations require some equipment that may not be available in-house to a local roads crew; this equipment is, however, generally available from private contractors. Where localities have convenient access to central plant facilities, this approach should be given strong consideration despite higher costs.

Central Plant Operations: In most central plant operations, predetermined quantities of lime, fly ash, water, and aggregate are fed into a continuous type pugmill; the blended mixture is then shuttled into a surge hopper where it may be loaded into

open-bed dumptrucks (see Figure 8). If the distance to the job site is long (approximately 20 or more miles), provision should be made to cover the LFA mix to prevent moisture loss or dust blow-off.

Mobile mixing plants have been used on local and state LFA stabilization projects to reduce transportation costs.

Once at the job site, several types of equipment can be used to spread the pre-mixed LFA. Automated equipment including spreader boxes, asphalt laydown machines and other similar equipment is recommended; automated equipment helps to ensure uniformity of depth and prevents segregation of the lime, fly ash, and aggregate. An alternative approach involves wind-rowing the LFA mixture, followed by spreading with road graders. This approach is not recommended as drying and segregation can occur, resulting in reduced strength gain, reduced durability of the stabilized base, and formation of compaction planes.

The LFA mix should be placed at approximately 20-30% greater depth than the desired final depth. Some experimentation prior to full-scale construction should be conducted. Compaction will depend on the type of aggregate, and method of spreading and compaction; but compaction must be to maximum density for adequate compressive strengths to develop.

In-Place Operations: With in-place operations, lime, fly ash, water, and aggregate are mixed and spread at the road site. While in-place mixing of LFA materials has produced satisfactory results, the final quality of the stabilized base rarely attains that of central plant operations of equal depth. In-place mixing, however, is usually the most economical approach for stabilization of roads with low-traffic volumes. The most apparent advantage is that in-place aggregate can be used in the mix, avoiding the cost of transporting aggregate to and from the central plant.

Lime can be placed either in a dry or slurry form. Pneumatic tanker trucks are commonly used to transport and place

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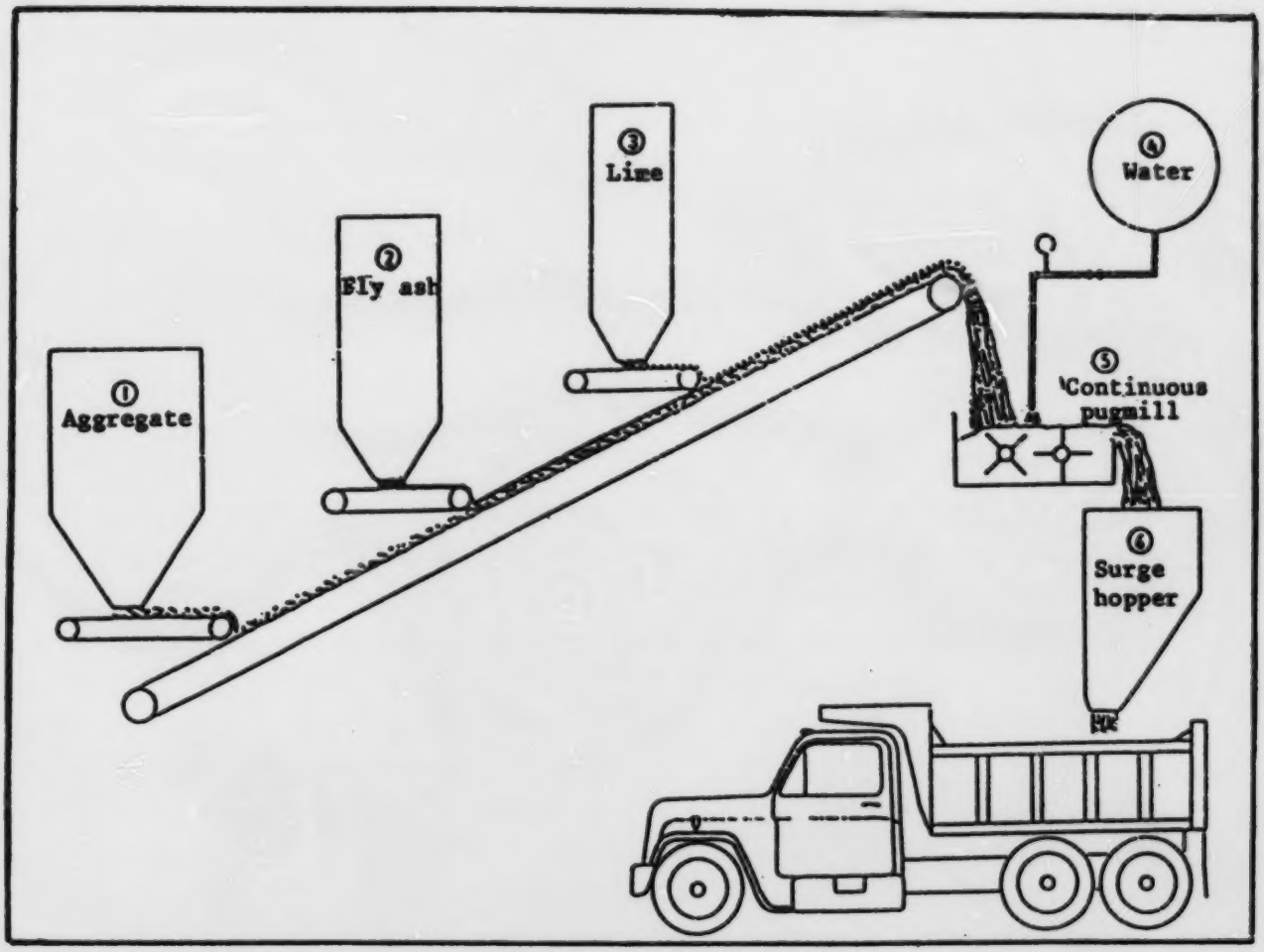

FIGURE 8. SCHEMATIC DIAGRAM OF TYPICAL PLANT LAYOUT FOR LFA MIXES.

From: Lime-Fly Ash-Stabilized Bases and Subbases, National Cooperative Highway Research Program (#37), Transportation Research Board, Washington, DC; 1976.

lime at the job site; problems include possible severe "dusting" and difficulty in attaining uniform lime distribution. If the dry form of lime is used, it should be spread before the fly ash is placed; fly ash is heavier than lime and will tend to hold down the dry lime, reducing (but not eliminating) dusting problems. Spreading lime in slurry form avoids the dust problem but is more costly due to the increased hauling costs for water; a lime slurry may contain more water than necessary for the LFA mix. Additionally, excess moisture in the final LFA mix may cause difficulties during compaction. Several LFA projects have used the dry form of lime for in-place mixing operations despite its drawbacks.

For in-place operations, fly ash is typically trucked to the job site and spread with spreader boxes or equivalent equipment. As with dry lime, spreading of fly ash may result in dusting problems and a lack of uniform distribution.

If a lime slurry is not used, water tanker trucks can be used to attain optimum moisture values for the in-place LFA mix.

Mixing of lime, fly ash, water, and aggregate is commonly performed with rotary mixers (pulvimixers) during in-place operations. Rotary mixers ensure thorough mixing, unlike mixing attempted with road graders which may result in layering of materials by particle size.

The LFA mix should not be placed in less than four inch lifts. To prevent longitudinal cracking, the LFA mix should be spread and compacted at full road width. If (to maintain traffic flow) a half width is placed at a time, care must be taken to eliminate a longitudinal seam.

Compacting

Correct compaction procedures are essential to achieving a satisfactorily stabilized LFA base. Compaction to maximum density (at optimum moisture content) is essential if the lime, fly ash, and aggregate mix is to develop the compressive strengths and freeze-thaw resistance demonstrated in the laboratory test-

ing of the mix design.

Once spread, the mix should be compacted from the bottom - up (i.e. compaction should initiate at the bottom portion of the mix and continue towards the surface); a sheep's foot compactor is recommended for this step. Following bottom-up compaction, pneumatic-tired rollers, vibratory rollers or vibratory pans can be used to compact the mix in preparation for surface grading.

Compaction of the LFA mix should be completed as quickly as possible after spreading to prevent loss of moisture and to avoid compaction difficulties due to self-hardening. Most specifications recommend that compaction should be finished on the same day as spreading, and often no later than four hours after the LFA mix has been placed. This caution is particularly critical when highly reactive fly ashes (i.e. lignite and sub-bituminous fly ashes) are being used.

Grading

A road grader can be used to shape the final crown of the stabilized road. Following this step, a steel-wheeled roller and/or pneumatic-tired roller is used to produce a smooth and well compacted final surface.

Sealing and Surfacing

A surface seal is critical to the strength gain and durability of the LFA stabilized road. A primer coat* should be

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*Cutback primers (with sand blotters) are recommended. Emulsion primers have resulted in "stripping" of the chip seal from the road surface. Selection of a satisfactory emulsion primer involves a complicated analysis of the surface charge ("zeta" potential) of the stabilized road; compatibility of charges between emulsion primer and road surface will reduce, but not entirely eliminate, the risk of stripping. Stabilized roads treated with cutback primers have not experienced the problems associated with use of emulsion primers; cutback primers have resulted in much improved surface coat performance. Current legislation in several states has banned the use of cutbacks in all circumstances except as used in primers.

placed immediately following final rolling/compaction to eliminate excessive moisture loss (maintaining the pre-determined optimal moisture level is absolutely necessary for desired strength gain and durability). A sand blotter placed over the primer will aid the curing process of both the primer and LFA mix. Following the required primer cure period (usually between one to three days), a chip seal or other asphalt protective surface coat should be applied. Without a protective surface coat, moderate traffic volume will rapidly cause abrasion of the surface of the stabilized road.

Maintenance

LFA stabilization of unpaved roads can bring clear benefits to local road maintenance operations, including elimination of seasonal grading* and addition of supplemental aggregate. Problems associated with dust and washboarding are also eliminated.

LFA stabilization does not, however, guarantee a maintenance-free road. Past projects have reported difficulties with the development of shrinkage cracks in the LFA stabilized base. Transverse shrinkage cracks are associated with the curing process of many cementitious products (e.g. portland cement, LFA, etc.). With a double chip seal, it is unlikely for most cracks that develop in the base to reflect up through the surface to a degree to require maintenance; (cracks that do reflect through the chip seal will probably not open widely enough to accept a joint sealer and will be re-sealed by continued traffic).

A double layer chip seal is a cost-effective surface coat for an LFA road base. A chip seal will, however, require periodic maintenance over the years. Several communities that have protected their stabilized road with a chip seal have added an additional chip seal layer every several years. This approach

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*An LFA stabilized road must not be graded. Disturbing the stabilized base will return it to its pre-stabilized condition; re-compaction alone will not re-stabilize a graded LFA base.

to maintenance not only protects the road from deterioration, but also tends to improve the load bearing capacity over a multi-year period.

SUMMARY

In deciding to upgrade an unpaved road, the local roads superintendent should choose among the available cost-effective alternatives; for secondary roads, lime-fly ash base stabilization can yield load bearing capacities sufficient to meet most requirements.

The life cycle costs of the alternative approaches to upgrading should be evaluated. Where quality lime and fly ash are available at a reasonable cost, LFA base stabilization with a protective surface seal can compare very favorably with the life cycle costs for upgrading with asphalt mats.

Whether stabilizing a road base using an LFA aggregate or an LFA aggregate-soil mix, a range of economical mix designs will have to be selected for the lime, fly ash, and aggregate (or aggregate-soil) mix. Laboratory tests on these designs will identify a mix design which specifies the relative percentages of lime, fly ash, and aggregate to be used in the stabilization project. The structural requirements of the road will determine the required thickness of the stabilized base. This required thickness will then allow an estimate of the quantities of materials needed for stabilization. The costs of these materials can then be estimated.

An understanding of the construction procedures involved in stabilizing a road base with lime and fly ash, i.e. mixing and spreading (using either central plant or in-place procedures), compacting, grading, and surfacing, will enable the roads superintendent to determine the approximate manpower and equipment costs for constructing an LFA stabilized base.

If the local government should decide to proceed with the LFA stabilization project, it may decide to secure consulting or contractual assistance for its first project. An understanding of the necessary testing and construction procedures will be of help to the roads superintendent in preparing a request for bids and in monitoring a first LFA stabilization project.

LFA stabilization of an unpaved road can eliminate the need for seasonal grading and addition of supplemental aggregate.

An LFA stabilized base can provide an excellent working platform for future road improvements. An LFA stabilized road initially protected with a double chip seal can be significantly improved over a 10-15 year period by placement of additional chip seals. This approach to maintenance/improvement of LFA stabilized roads will help to protect the initial investment in the stabilized road, and keep pace with traffic volume growth over a multi-year period (as well as spreading the capital costs over many years).

APPENDIX A

ESTIMATING THE COSTS OF AN LFA AGGREGATE-SOIL BASE STABILIZATION PROJECT

APPENDIX A

ESTIMATING THE COSTS OF AN LFA AGGREGATE-SOIL BASE STABILIZATION PROJECT

As described in section 2 of this report, five to six inches or more of aggregate is desirable for adequate lime-fly ash stabilization of low traffic volume unpaved roads. Often, however, unpaved roads contain less than the minimum five inch depth of in-place aggregate, requiring addition of supplemental aggregate to achieve the desired depth. An alternative (and generally less costly) approach involves LFA stabilization of a mixture of in-place aggregate and subgrade soils to a total minimum depth of seven to eight inches.

In addition to the greater thickness required, several drawbacks are associated with aggregate-soil base stabilization, including relatively slow strength development (compared to aggregate base stabilized roads) and initial susceptibility of the soil component to frost. These drawbacks are magnified as the ratio of soil to aggregate increases. LFA base stabilization of aggregate-soil mixes has, however, resulted in satisfactory performance of low traffic volume roads while eliminating the expense of supplemental aggregate.

Construction Materials

Aggregate and Soil: A base aggregate-subgrade soil mixture should ideally have the same properties as a quality aggregate for use in an LFA base stabilization project, i.e. well graded, durable particles, etc.

Addition of lime and fly ash will have differing effects on combinations of aggregate with various soils: two broad categories of soils, and their suitability for mixing with aggregate for LFA stabilization, are as follows:

Clays: Many clays contain alumina and silica which react with lime, and which set up much like a lime-fly ash product (see Figure 1 -pg.5) Addition of lime will also reduce the plasticity of some clays, providing improved load bearing support and workability during mixing and compaction of the aggregate-soil mix. Use of lime alone has adequately stabilized these clays (particularly montmorillonite clays), although addition of both lime and fly ash to an aggregate-clay soil mixture will produce better strength gains and durability than lime alone.*

Silts: Silty soils may exhibit some degree of pozzolanic reactivity (i.e. contain aluminas and silicas), particularly silty soils containing clay. Addition of lime alone is rarely appropriate for stabilization of this soil type; while some improvement of soil properties can occur, the major advantage of base stabilization with silty soils is the use of these soils as an aggregate fine, i.e. for their structural qualities rather than for their reactive properties.

Fly Ash: As with LFA aggregate stabilization, the reactivity of the fly ash will have a significant impact on the final strength and durability of the LFA-aggregate-soil mixture.

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*Caution: The quantity of lime needed to reduce the plasticity of clays is lost to the pozzolanic cementitious reaction. Therefore, the mix design should be appropriately adjusted to either include a larger quantity of lime, or stabilization should occur in two stages: 1) pre-treatment of the aggregate soil with lime to reduce plasticity, and 2) addition of lime-fly ash for the pozzolanic process.

Lime: Again, hydrated lime and quicklime have been used successfully for LFA aggregate-soil stabilization. Limestone (i.e. calcium carbonate) should not be used for LFA aggregate-soil stabilization. Kiln dust has been used with success in aggregate-soil stabilization projects; the same cautions and drawbacks described for aggregate stabilization (see Appendix B) apply. Finally, portland cement can be an effective additive in aggregate-soil stabilization, providing free calcium to the reaction, with other benefits, as well.

LFA Mix Design

The relative amounts of lime and fly ash in the mix design will vary according to the type of aggregate-soil mixture to be stabilized. As a general rule, greater quantities of lime-fly ash are required for aggregate-soil base stabilization than for aggregate base stabilization; (as the ratio of soil to aggregate increases, the amount of lime and fly ash generally increases to about 15-25 percent). Pozzolanic clays containing alumina and silica (see pg. 34) react with lime and fly ash; these clays typically require smaller quantities of lime and fly ash than non-pozzolanic clays to produce required strength and durability values. Table A-1 lists several fine-grained soils and the relative amounts of lime, fly ash, and water to produce given strengths.

Testing the LFA Mix: Once the preliminary mix design of the aggregate-soil mixture has been determined, strength gain and durability tests are conducted*. As with aggregate mixtures, ASTM

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*As with LFA aggregate mixes (no subgrade soil), the required thickness of the stabilized base will have to be determined before testing begins so that a representative sample of the aggregate-soil (that is, samples that contain representative percentages of in-place aggregate and subgrade soil) can be used in the design mixes to be tested. If, for example, thickness design determines that seven inches of subgrade soil is to be incorporated with three inches of in-place aggregate, this 70%-30% mixture of aggregate-soil will be needed in testing of the various mix designs. An acceptable mix design must achieve minimum compressive strength and durability values.

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SOIL TYPE	FLY ASH	ADMIXTURE %	RATIO LIME:FLY ASH	Maximum Dry Density - Opt. Moisture Content		UNCONFINED COMPRESSIVE STRENGTH		
				pcf (kg/m^3)	%	Days	psi	(kPa)
North Dakota Clay	-	0	0	104.6 (1676)	21.4	-	57	(390)
	Ottertail (lignite)	24	1:5	102.7 (1645)	19.9	0	241	(1660)
						7	464	(3200)
	Basin (lignite)	20	1:4	104.9 (1680)	20.4	0	231	(1590)
						7	396	(2730)
North Dakota Silty Clay	-	0	0	112.5 (1802)	6.7	0	87	(600)
	Ottertail (lignite)	20	1:4	114.0 (1826)	15.4	0	112	(770)
						7	532	(3670)
	Basin (lignite)	20	1:4	113.6 (1820)	15.2	0	124	(850)
						7	444	(3060)
Arkansas Malinite Clay	(western)	0	0	97.5 (1562)	20	7	190	(1310)
		10	0:10	101.2 (1621)	18	7	305	(2100)
		20	0:20	102.6 (1643)	17.5	7	410	(2830)
Missouri Clay	-	0	0	98 (1750)	24	0	28	(190)
	Hawthorne	15	0:15	95 (1522)	26.5	0	21	(140)
						3	56	(390)
						28	204	(1410)

TABLE A-1. STRENGTH VALUES FOR SOME LIME-FLY ASH STABILIZED FINE-GRAINED SUB-BASE SOILS.

Adapted From: Fly Ash: A Highway Construction Material, 1976, p. 118.

C593 (see pg. 13 & 16) determines these values. Cylinders containing varied quantities of lime, fly ash, aggregate-soil, and water are formed. Because aggregate-soil mixtures gain strength slowly relative to aggregate mixtures, a 28 day curing period (rather than seven day) at 70°F is recommended for aggregate-soil mixtures. As with aggregate mixes, acceptable compressive strength and vacuum saturation (durability) values are used to identify an acceptable mix design.

Thickness Design (Of an Aggregate-Soil Base)

An estimate of the required thickness of the stabilized base course will be necessary in order to calculate the quantity of materials needed to complete the stabilization project. Depending on the quality of the soil components, an aggregate-soil mix may not achieve the compressive strength of a well graded aggregate mix. Marginal aggregate soil mixes with compressive strengths of about 400 may have structural coefficients of less than 0.28. Additionally, an aggregate-soil mix will have an initial susceptability to frost because of relatively slow strength development. Consequently, a greater thickness (minimum of seven to eight inches) of an LFA aggregate-soil mix is usually placed than would be required for an LFA aggregate (no subgrade soil) mix.

The required thickness of an LFA aggregate-soil stabilized base can be estimated in the same way as for an LFA aggregate stabilized base (see Figure 5, p. 19). Although a mixture of aggregate and subgrade soil will be used in the mix, only the thickness of the in-place aggregate should be considered for "C" in the equation (Figure 5).

In the following example approximately five inches of subgrade soil would have to be scarified in addition to the three inches of in-place aggregate. This eight inches of aggregate-soil would be combined with lime and fly ash in the stabilized base.

Example: A = 5

B = 0.4

C = 3 ; three inches of in-place aggregate base to be scarified. Several inches of subgrade soil to be also scarified.

$$T = \frac{5 \times 0.4 + (0.1 \times 3)}{0.28} = 8.2 \text{ inches*}$$

Construction Procedures (For Aggregate-Soil Stabilization)

The same construction season caution for base-stabilized roads applies to aggregate-soil base stabilized roads (see Figure 6 - pg. 21).

Construction procedures described for aggregate base stabilization can be applied to aggregate-soil base stabilization with the following exceptions.

Mixing and Spreading

Because aggregate-soil stabilization requires use of in-place soils, central plant operations are generally not cost-economical for these stabilization projects. While in-place operations may be necessary, the resulting quality of the stabilized road is usually less than that obtained with central plant operations.

Mixing equipment described for in-place base stabilization operations are also appropriate for aggregate-soil stabilization (see pp. 24-26). Extra care should be taken to avoid layering of materials (i.e. ensure efficient mixing). Prior to compaction, trench the mixed materials and examine the color of the mixture; streaks or layers in the LFA-aggregate-soil mix indicate non-uniform mixing; this area should be remixed.

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*For aggregate-soil mixes with marginal compressive strengths of about 400, a structural coefficient of less than 0.28 should be used (0.23). In this example the result would then be a required thickness of 10 inches.

Compacting and Grading

Compaction procedures for an aggregate-soil stabilized base are the same as described for aggregate stabilization with the exception that vibratory rollers or pans should not be used on fine-grained aggregate-soil mixtures. Following bottom-up compaction, a pneumatic-tired roller should be used.

Sealing and Surfacing

Due to the susceptibility of fine-grained soils to deterioration under freeze-thaw conditions, special care should be taken to ensure that a quality protective surface coat is placed on an aggregate-soil stabilized base. Use of cutback primers (rather than emulsion primers) is recommended (see footnote - pg. 27) with a double layer of emulsion or cutback chip seal placed over the primer.

Maintenance (Of a Stabilized Aggregate-Soil Base)

Maintenance considerations for aggregate-soil stabilized roads are the same as described for aggregate base stabilization (see pg. 28-29), with the exception that special attention should be given to limiting the amount of heavy truck traffic allowed on the road for several weeks after construction because of the slower strength development of an LFA aggregate-soil stabilized base.

APPENDIX B

LFA BASE STABILIZATION MATERIALS; MIX DESIGN

APPENDIX B

LFA BASE STABILIZATION MATERIALS; MIX DESIGN

(Note: This appendix describes the materials and mix design considerations for LFA (aggregate) base stabilization. Materials and mix design considerations for LFA base stabilization using a mixture of aggregate and subgrade soil are covered in Appendix A.)

Aggregate: The type of aggregate and its particle size gradation will largely determine the amount of lime and fly ash necessary to achieve a desired load bearing capacity. A well graded aggregate (i.e. many different particle sizes) will generally require smaller quantities of lime and fly ash than a poorly graded aggregate (i.e. little range in particle sizes, particularly aggregates lacking fines). The aggregate should contain minimal amounts of organic materials and be comprised of hard, durable particles, although some softer aggregates (e.g. shale) can be pre-treated with lime to improve workability and durability for use in LFA stabilization.

Fly Ash: The reactivity of fly ash will have a significant effect on the final strength and durability of the LFA-aggregate mixture. A highly reactive fly ash (i.e. from sub-bituminous or lignite coal from the western regions) will generally produce greater strength and durability values over the short and long term than an equivalent amount of a less reactive fly ash. Reactive fly ashes contain a sizeable proportion of free calcium (see Figure 1 - pg. 5), reducing the amount of lime necessary for the pozzolanic reaction to produce required strength and durability values.

Even among the reactive fly ashes, however, the level of reactivity varies according to several characteristics of the fly

ash. The American Society for Testing and Materials (ASTM) has developed a testing procedure (ASTM C618) which identifies properties critical to the pozzolanic reaction*.

Lime: Free calcium is a necessary ingredient of the pozzolanic reaction (see Figure 1). Several forms of lime have been used to provide free calcium for LFA stabilization. Commercial hydrated lime has been used with the most success; quicklime has also been used but is a highly caustic compound and should be used in construction only in the slurry form to minimize safety hazards. Limestone (i.e. calcium carbonate) does not contain significant quantities of free calcium and should not be used for LFA stabilization. ASTM C821 provides specifications for lime for use in LFA stabilization.

Cement or lime plant kiln dust has been used (see Figure 1) as a source of free calcium for several LFA stabilization projects. Kiln dust is typically less costly than commercial lime; it does, however, often vary as much in quality as fly ash.

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*ASTM C618 is a specification for fly ash in portland cement; it does, however, identify certain properties critical to the pozzolanic reaction:

- Loss on Ignition (LOI): a measure of the relative amounts of unburned carbon in the fly ash - high LOI values (relatively large amounts of unburned carbon) may result in reduced strengths.
- Particle size: a measure of the distribution of fly ash particle sizes - fine fly ash is typically more reactive than coarse fly ash.
- Free Calcium Content: a measure of the relative amounts of uncombined calcium oxides - high values indicate highly reactive fly ashes.
- Alumina and Silica Content: a measure of the relative amounts of uncombined alumina and silica oxides - high values generally provide more "fuel" for the pozzolanic reaction.

As a general rule, sub-bituminous and lignite coal from the West produce fly ash with high levels of free calcium and moderate levels of alumina and silica oxides. LOI and particle size values depend on both the type of coal burned and the age and type of the power plant which produced the fly ash. These four properties can vary widely even within a single plant. Measurement of these fly ash properties not only can simplify determination of the relative amounts of lime, fly ash, water, and aggregate required, but can also identify fly ashes that are unacceptable for adequate LFA stabilization.

adding another variable to the mix design process. Additionally, an equivalent weight of commercial lime commonly contains a greater amount of free calcium, requiring proportionately greater quantities of kiln dust to achieve the same effect as a smaller quantity of commercial lime. Finally, lime or cement kiln dust-fly ash products are covered by patents issued in 1978-79; local government use of these products may require payment of royalty fees to the patent holder.*

Portland cement has also been used as an additive for LFA stabilization. Portland cement not only contributes free calcium, but also tends to hasten the completion of the pozzolanic reaction as well as reducing or eliminating undesirable expansion problems of certain LFA mixtures.

LFA Mix Design

The objective of the mix design process is to select an economical LFA mixture of lime, fly ash, and aggregate that will produce adequate strength and durability. The mix design will ultimately affect the quality of the road base and the overall costs of the materials. A variation of just one percent lime or fly ash content in the mix design can mean as much as 35 or more tons of this material per mile in the road base - thus the importance of an economical mix design. Several tentative mix designs should be laboratory tested; an acceptable mix must attain an adequate compressive strength and be resistant to freeze-thaw cycles.

The required quantities of fly ash and lime in the mix design will vary, depending not only on the properties of the lime and fly ash, but also on the quality of the aggregate to be stabilized. Particle size and type of aggregate will largely determine the relative amounts of pozzolanic materials necessary for adequate stabilization. As a general rule, an aggregate

*For information on these patents, contact: N-Viro Energy Systems, Ltd., 3450 W. Central Ave., Suite 250, Toledo, OH, 43606; (419) 535-6374.

without organic or chemical impurities (e.g. some A-7 clays are high in organics), of well graded particle size, and with strong and durable particles is best for LFA stabilization. Aggregates with a relative absence of fines will require proportionately greater amounts of fly ash and lime than well graded aggregates. At the other extreme, aggregates with an overabundance of fines will also generally require greater quantities of pozzolanic materials. The objective is to produce a firm, supporting matrix of lime and fly ash that surrounds and "locks" the aggregate into place.

The aggregate (as well as the lime and fly ash) used in the mix design should be the same as will be used on the job. *If a combination of in-place aggregate will be used with additional aggregate hauled in, then this combination of aggregates should be used in the design mixes tested in the laboratory.* The required thickness of the LFA base will have to be determined in order to determine the quantity (depth) of supplemental gravel to be added to the in-place aggregate. See page 16, *Thickness Design*.

Several procedures are used to estimate the relative quantities of lime and fly ash necessary for desired strength and durability of the LFA mix. The amount of lime and fly ash needed to fill the void space in the aggregate can be calculated. Alternatively, the quantity of lime and fly ash required to achieve maximum dry density of the mixture is determined. The mix design process, however, has been simplified as experience with LFA stabilization has grown; general categories of aggregate with optimum ranges of lime and fly ash are shown in Table B-1.

Because various combinations of lime, fly ash, and aggregate of various qualities will yield different test results, i.e. compressive strengths, several design mixes containing a range of percentages of lime, fly ash, and aggregate are tested

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	MIX AGGREGATE			
	CRUSHED STONE	GRAVEL	SAND	SLAG
MIX COMPONENT	(a) MIX PROPORTIONS - PERCENT BY WEIGHT[1]			
Aggregate	82 - 87-1/2	77 - 87-1/2	65 - 82	60 - 82
Fly Ash	10 - 14	10 - 18	15 - 30	15 - 35
Lime[2]	2-1/2 - 4	2-1/2 - 5	3 - 5	3 - 5
SIEVE SIZE	(b) AGGREGATE GRADATION - PERCENT PASSING			
1"	100	100	100	100
3/4"	90 - 100	90 - 100	100	100
1/2"	60 - 85	60 - 85	100	100
#4	50 - 75	50 - 75	90 - 100	90 - 100
#40	10 - 20	7 - 15	20 - 40	10 - 40
#100	2 - 5	3 - 6	0 - 3	0 - 2

[1]Based on total mix dry weight. [2]Lime or lime plus cement at a 3:1 ratio.

TABLE B-1. TYPICAL LFA MIXTURES

From: Fly Ash: A Highway Construction Material. James Meyers, Raman Pichumani, and Berndadette Kapples. Prepared for: Federal Highway Administration. May 1976 (p. 36).

for their strengths and durability at optimum moisture content*. An effort should be made to test design mixes which include lesser amounts of the more expensive materials since the design mix will obviously affect the overall costs of the project.

*Moisture content is critical to the pozzolanic reaction. Tests approved by the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM) describe a procedure for determining the optimum moisture content for LFA mixtures. The tests, AASHTO T 180-74 or ASTM D1557 (method C for each test) determine the optimal moisture content to achieve maximum dry density of the LFA mix (each test should be modified according to cylinder design procedures listed in ASTM C593).

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